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The Determination of the Extraterrestrial Constant of a Dobson Spectrophotometer

by R. A. HAMILTON, O.B.E., M.A. and J. M. WALKER, M.Sc., D.I.C.

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The Determination of the Extraterrestrial Constant of a Dobson Spectrophotometer

By R. A. Hamilton, O.B.E., M.A. and J. M. Walker, M.Sc., D.I.C.

SUMMARY

The extraterrestrial constants of Dobson spectrophotometer No. 7 were determined by solar observations in clear weather at Lerwick in 1963, and by comparison with spectrophotometer No. 1 in 1966. The values of the constants thus determined are in satisfactory agreement with one another and with the original determinations by comparison with No. 1 in 1950. It appears that there has been no appreciable cyclic change in the relative intensities of the ultra-violet bands of the solar spectrum which are used in the ozone measurements: such a change would be interpreted as a global cyclic change in the amount of ozone. The extraterrestrial constants for moon observations were also measured.

1. INTRODUCTION

The Dobson spectrophotometer has been the instrument in most general use since 1931 over an increasing network of stations for the measurement of the total amount of atmospheric ozone. The instrument is fully described in the IGY Instruction Manual.[1]* The extraterrestrial constants (to be discussed below) of spectrophotometer No. 1 were determined at Arosa in 1950, and those of all other spectrophotometers have been determined by direct comparison with No. 1. Very few other measurements of extraterrestrial constants have been made. This paper describes the experiments carried out at Lerwick in 1963 to determine the extraterrestrial constants of spectrophotometer No. 7 both for sun and for moon observations.

2. THEORY

Attenuation of radiation in the atmosphere

Let: I_0, I_0' be the intensities per unit waveband of solar radiation of wavelengths λ, λ' just outside the earth's atmosphere.

I, I' be the intensities per unit waveband of solar radiation of wavelengths λ, λ' falling on the spectrophotometer.

x be the amount of ozone in one vertical thickness of the atmosphere expressed as the thickness in cm which this amount of ozone would occupy if concentrated into a uniform layer of pure gas at s.t.p.

Z be the sun's zenith distance.

μ be the ratio of the path-length of sunlight through the ozone layer (supposed to be situated at 22 km) to the vertical path-length through the ozone layer.

m be the ratio of the path-length of sunlight through the atmosphere, allowing for refraction and curvature of the earth, to the vertical path-length through a standard atmosphere.

α, α' be the absorption coefficients of ozone for wavelengths λ, λ'.

β, β' be the scattering coefficients due to air molecules for a vertical ray in a standard atmosphere for wavelengths λ, λ'.

δ, δ' be the attenuation coefficients due to aerosol for a vertical ray in a standard atmosphere for wavelengths λ, λ'.

* The index figures refer to the bibliography on page 11.

The classical laws of attenuation give

$$\log I=\log I_0-\alpha\mu x-\beta m-\delta\sec Z$$
$$\text{and } \log I'=\log I_0'-\alpha'\mu x-\beta' m-\delta'\sec Z.$$
$$\text{So } (\alpha-\alpha')\mu x+(\beta-\beta')m+(\delta-\delta')\sec Z=N \quad \ldots \quad (1)$$
$$\text{where } N=\log I_0/I_0'-\log I/I' . \quad \ldots \quad (2)$$

Attenuation of radiation in the spectrophotometer

The solar radiation of intensity I falls on the first slit of the spectrophotometer and after refraction passes through a slit of width S which allows radiation of bandwidth $d\lambda$ to pass through it. The energy passing through the slit, therefore, is $Id\lambda$. After subsequent refraction this radiation falls on the photomultiplier; if p is the sensitivity of the photomultiplier, i.e. the current produced by unit energy of the incident radiation, the photomultiplier current is $pId\lambda$. It has been assumed that no attenuation has occurred in the optical parts; this can be taken into account by writing the photomultiplier current as $apId\lambda$ where a is the attenuation factor.

For the radiation of wavelength λ' passing through the other slit with bandwidth $d\lambda'$ the corresponding current would be $a'p'I'd\lambda'$, but this radiation is further attenuated by an adjustable optical wedge by a factor 10^t, where t is the optical thickness of the wedge.

When measurement is made with the spectrophotometer these two currents are made equal by adjusting the wedge. Then $\log a/a'+\log p/p'+\log d\lambda/d\lambda'+\log I/I'+t=0$

$$\text{or } P+\log I/I'+t=0 \quad \ldots \quad (3)$$
$$\text{where } P=\log a/a'+\log p/p'+\log d\lambda/d\lambda'.$$

The optical thickness t is related to the dial reading R by an equation of the form $t=W(R-R_0)$ where W, a slowly changing function of R, is the wedge constant of the spectrophotometer, and R_0 is the zero reading of the dial, i.e. the reading for which the optical thickness is zero. Equation (3) can now be written $\log I/I'+P+W(R-R_0)=0 \quad \ldots \quad (4)$

The extraterrestrial constant

Combining (2) with (4) we get

$$N=\log I_0/I_0'+P+W(R-R_0) \quad \ldots \quad (5)$$
$$=L_0+W(R-R_0). \quad \ldots \quad (6)$$

The quantity L_0 is usually referred to as the extraterrestrial constant of the spectrophotometer. It consists of two parts, a solar part, $\log I_0/I_0'$ which depends only on the solar spectrum, but which may vary (during the solar cycle), and a part P which depends only on the individual spectrophotometer, and which may also change. In practice the extraterrestrial constant is never determined explicitly: if an observation were made just outside the earth's atmosphere, the thickness of the optical wedge would be $-L_0$.

Later, changes in the extraterrestrial constant will be discussed, and to avoid this anomaly we define a solar spectrophotometer index T, where

$$T=L_0-WR_0 \quad \ldots \quad (7)$$
$$\text{and thus } N=WR+T \quad \ldots \quad (8)$$

Thus T differs from L_0 by the quantity WR_0, which depends only on the individual spectrophotometer. Thus T contains a solar and a spectrophotometer part, and it can be seen that it is the value of N when the dial reading R is zero.

3. CALIBRATION OF SPECTROPHOTOMETERS

General remarks

In order to enable the ozone thickness x to be determined from (1), wedge calibration tables relating N to R must be computed. To do this T in (8) must be determined.

To determine T, observations are made in clear atmospheric conditions (when it can be assumed that $\delta-\delta'=0$) on days when it may be assumed that the ozone amount x remains constant. Then from (1) and (5)

$$WR=(\alpha-\alpha')x\mu+(\beta-\beta')m-T.$$

Thus $WR-(\beta-\beta')m$ varies linearly with μ, and if it is plotted against μ and the line extrapolated to $\mu=0$ the extraterrestrial constant T is given by the value of $WR-(\beta-\beta')m$. This method of calibration will be described and discussed more fully later.

Spectrophotometer No. 1 was calibrated at Arosa in 1950 and its index T_1 was evaluated. Owing to variations in P from one spectrophotometer to another the values of T (and L_0) will vary from one instrument to another. All spectrophotometers have been calibrated by comparison with No. 1 or with a sub-standard such as No. 2. Simultaneous direct-sun observations are made by the two instruments and from (1) and (5)

$$N=T+WR=T_1+W_1R_1.$$

W and W_1 are determined in the laboratory and thus from the simultaneous readings R and R_1, the index T can be evaluated.

A wedge calibration table, relating N to R—referred to henceforth as the R–N table—can now be calculated from (8). When an ozone observation is made, the value of N corresponding to the observed dial reading R is read from this table, and x, the ozone amount, is calculated from (1).

The wavelength-pairs in present use

In the early days the mean wavelengths of the two wavelength-pairs used were 3110 and 3265 Å. In the 1950's other wavelength-pairs came into use: pair A (3055 and 3254 Å), pair B (3088 and 3291 Å), pair C (3114 and 3324 Å) and pair D (3176 and 3398 Å). The values of the extraterrestrial constants for each of these wavelength-pairs for instrument No. 1 were determined at Arosa in 1950.

Most routine observations are made by combining simultaneous A and D observations, as in this way the effects of haze are eliminated: these are known as AD observations.

The absorption and scattering coefficients for these wavelength-pairs which have been used in this investigation are those given in the IGY Manual.[1]

The 1957 Oxford extraterrestrial constant measurements

The extraterrestrial constants for instrument No. 1 were redetermined in 1957 at Oxford by Dobson and Normand.[2] Observations were made for all wavelength-pairs at varying solar zenith distances. Thirty-one sets of observations were made, each set consisting of three observations in a half-day, near noon and when μ had values of approximately 2 and 3. Trouble was experienced with changes in the atmosphere, whether in ozone or haze, during the course of a set of observations, and no attempt was made to estimate the rate of change of ozone amount although, as will be shown later, such changes gravely affect the results. The authors emphasize that Oxford has a most unsuitable atmosphere for this calibration experiment.

Of the 31 sets of observations 14 were rejected as being liable to large variations in ozone because of haze, and the accepted corrections to the previously accepted values of T were derived from the remaining 17 sets. The mean values for the 17 selected days, and from the 14 other days were as follows:

	Corrections to T			
Wavelength-pairs	A	B	C	D
From 17 selected days	+0·032	+0·021	0	−0·003
From 14 other days	+0·013	−0·005	−0·012	−0·017

The error of the mean values for the 17 selected days was estimated to be about ±0·010 or less.

Spectrophotometer No. 7 at Lerwick 1950–63

Spectrophotometer No. 7 was calibrated for wavelength-pairs *A*, *C* and *D* by comparisons with No. 1 in 1950, and sent to Lerwick. Observations on wavelength-pair *C* began in May 1951.

In 1957 the instrument was inspected at Lerwick. No change was made in the *R–N* tables for the *C*-pair: new *R–N* tables for *A*- and *D*-pairs were issued as the wedge constants had apparently changed: the new tables fitted the 1950 tables at $R=140$ and $R=60$ for *A*- and *D*-pairs respectively.

In 1962 a further calibration by standard lamps was made. When lamps U4 and 57B were used with spectrophotometer No. 7 the *N*-values, read from the observed values of *R* in the Lerwick *R–N* tables, were lower than the *N*-values obtained when these lamps were used with the sub-standard No. 2. Accordingly the values of *N* in the *R–N* tables were increased, at $R=50$, by 0·056, 0·023 and 0·010 for *A*-, *C*- and *D*-pairs respectively.

The reason for these large changes was not understood at the time, and it was decided to calibrate No. 7 during the summer of 1963 by solar observations on the lines described above.

4. THE 1963 LERWICK CALIBRATION

Introduction

In view of the difficulties experienced in the 1957 Oxford calibrations it was decided to make observations only in very clear weather, and to attempt to eliminate the effect of variations in the ozone amount, firstly by making more frequent observations during the period when μ is changing rapidly, and generally omitting the period of a few hours around noon when μ is changing only slowly, and secondly by rejecting sets of observations during which the observations themselves indicated that the amount of ozone was varying appreciably or when a careful examination of the meteorological conditions suggested that the amount of ozone was likely to be changing appreciably. In view of the high average cloudiness of Lerwick it was not expected that many suitable half-days would be experienced, but fortunately there was a period of very clear weather at the beginning of June 1963.

Theory

The extraterrestrial constants were evaluated by determining the errors in the 1962 tables: this is the method of Dobson and Normand.[2]

All observations were made in very clear atmospheric conditions so that the aerosol attenuation term $(\delta-\delta')\sec Z$ in (1) can be neglected.

For a given wavelength-pair let ΔN be the correction which must be added to the tabulated values of *N* to give the true value:

$$\text{then from (1)} \quad N+\Delta N=(\alpha-\alpha')\mu x+(\beta-\beta')m$$
$$\text{so} \quad N/\mu+\Delta N/\mu=(\alpha-\alpha')x+(\beta-\beta')m/\mu.$$
$$\text{Write} \quad p=N/\mu-(\beta-\beta')m/\mu$$
$$\text{and} \quad q=1/\mu$$
$$\text{then} \quad p+q\Delta N=(\alpha-\alpha')x$$
$$\text{and} \quad \Delta N=-\mathrm{d}p/\mathrm{d}q+(\alpha-\alpha')\mathrm{d}x/\mathrm{d}q.$$

From this equation it can be seen that if the amount of ozone is constant and *p* is plotted against *q* the points will lie on a line the gradient of which is $-\Delta N$.

In practice it is not valid to assume that the ozone amount *x* remains constant over a period of hours, for a small change of ozone amount can cause important changes in the slope of the (p, q) line. If the ozone changes by 0·001 cm per hour, which would be regarded as a small change, and *q* changes from 0·40 to 0·65 in a period of about 2 hours, then

$$\mathrm{d}x/\mathrm{d}q=0{\cdot}002/0{\cdot}25=0{\cdot}008,$$

so this small change in ozone causes a change in slope varying from 0·004 for D-wavelengths to 0·014 for A-wavelengths. More rapid changes of ozone amounts, however, are likely to occur quite often, and quite a large variation in the measured values of the slope of the (p, q) line may be expected.

The experimental work

On each day which promised to be favourable, observations began as soon as μ was approximately 3, and continued as long as weather conditions permitted. On each occasion a series of readings were taken on wavelength-pairs A, C and D within a period of about five minutes. Such a series of observations was made about three times an hour when μ was changing rapidly and roughly at hourly intervals around noon. On 29 May as many as 26 series of observations were made, consisting of 104 observations. All the observations were made in a clear atmosphere, those on 29 May and afterwards in exceptionally clear conditions.

Nineteen sets of observations were obtained but eight of these were rejected as it was clear that the ozone amount was changing quite quickly or irregularly. Even in the case of the remaining eleven sets, fluctuations in the ozone amount made it difficult to determine the slopes of the (p, q) lines. To avoid subjective errors the regression equations were calculated and normally there were about eight points on each line in the range $q=0{\cdot}40$ or slightly less to $q=0{\cdot}65$ or slightly more.

The slopes of the regression lines are shown in Table I, together with a remark as to whether the meteorological conditions, discussed in the next section, led to the value's being estimated as high or low.

TABLE I. *Slope of regression equation for wavelengths A, B, C and D*

Date	Forenoon					Afternoon				
1963	*A*	*B*	*C*	*D*	Estimate	*A*	*B*	*C*	*D*	Estimate
9 May						0·061	0·069	0·040	0·035	High
19 May	0·068	0·059	0·045	0·034	High			0·027		Low
22 May						0·045	0·038	0·021	0·018	
23 May	0·081	0·067	0·055	0·045	High	0·017	0·004	0·004	0·000	Low
1 June	0·065	0·052	0·041	0·037						
3 June	0·019	0·020	0·017	0·021		0·047	0·040	0·026	0·026	
4 June	0·050	0·048	0·034	0·037						
5 June						0·040	0·042	0·037	0·046	

Review of the meteorological conditions

It has been shown above that small changes in the ozone amount have a marked effect on the slope of the regression line, and the frequent observations during the day have shown that normally there are quite appreciable fluctuations in ozone amount even when the meteorological situation would lead one to expect it to be steady. It is very important, therefore, to study the meteorological conditions very carefully. It is not sufficient to rely on using a statistically large number of sets of observations so that the net effect of ozone change may be regarded as eliminated, for calibration observations can only be made under certain weather conditions: they cannot, for instance, be made in the cloudy weather ahead of a warm front when the ozone amount is decreasing, but are more likely to be made well behind a cold front when the ozone amount increases. The choice of observation times is not random, and it cannot be assumed that on the average the amount of ozone is not changing.

Accordingly for each set of observations the meteorological conditions have been carefully examined, and an estimate has been made of the probable trend of the ozone amount on the basis

of the position of the weather system and the known negative correlation between ozone amount and the height of the tropopause. An estimate of the trend during the day can also be made on days when observations are made at times of equal μ in forenoon and afternoon, and the general trend is seen from the daily noon measurements of ozone amount. Data used in estimating the changes of ozone amount are given in Table II.

TABLE II. *Summary of meteorological conditions*

Date (D) 1963	Midday value of ozone			Tropopause height on day D			Meteorological analysis
	D−1	D	D+1	0000	1200	2400*	
	centimetres			*kilometres*			
9 May	0·417	0·439	0·412	8·6	7·8	10·1	Rapidly moving depression west of Ireland and old depression over Iceland.
19 May	0·418	0·415	0·402	9·1	7·6	9·4	Complex showery situation.
22 May	0·432	0·415	0·393	8·2	7·8	9·3	East side of weak slowly moving ridge of high pressure.
23 May	0·415	0·393	0·380	9·3	10·0	10·1	Depression over Ireland moving S.E. Anticyclone over Norway.
1 June	0·377	0·375	0·373	11·0	11·3	11·3	Anticyclone over Norway.
2 June	0·375	0·373	0·383	11·3	11·1	11·0	Anticyclone between Lerwick and Norway.
3 June	0·373	0·383	0·353	11·0	11·1	11·4	Anticyclone slightly north of Lerwick. Cold front approaching.
4 June	0·383	0·353	0·358	11·4	11·7	12·0	Weak cold front just passed Lerwick.
5 June	0·353	0·358	0·370	12·0	11·9	11·8	Depression over Biscay, anticyclone over Iceland.

*times are GMT

Daily analysis of the meteorological conditions

On 9 May a weak front passed at noon, and during the afternoon the tropopause rose quickly, and a decrease of ozone is probable—there was a fall of 0·027 cm by noon on the following day. The slopes can be expected to be too high.

On 19 May observations were made during the forenoon in clear periods between occasional showers: only *C* observations were made in the afternoon. The tropopause was falling, and afternoon ozone amounts were higher than in the morning. The slopes may be expected to be too high in the forenoon and too low in the afternoon.

On 22 May Lerwick was on the east side of a weak, slowly moving ridge of high pressure and little change of ozone was expected. The tropopause rose in the afternoon, indicating a slight decrease of ozone, and the general trend was negative. Observations were possible only in the afternoon and the slopes can be expected to be approximately correct (slightly high).

On 23 May the ozone amount was higher in the afternoon than in the morning, though the general trend was negative, and the tropopause rose. It is probable that the slopes in the forenoon are too high and in the afternoon too low—the mean values 0·048, 0·041, 0·029 and 0·023 are close to the values quoted below.

Undoubtedly the best measurements were those made in the very fine spell of weather at the beginning of June 1963. An anticyclone moved into the Shetland area on 29 May, and was almost stationary until it moved to the Iceland area on 5 June. The observations of 29 May, however,

showed that the ozone was fluctuating so much and so irregularly that no reasonable (p, q) line could be drawn and both the forenoon and afternoon sets have been rejected. Then, after two cloudy days, a spell of brilliantly clear weather followed, almost unprecedented in recent years, with a very clear atmosphere. Table II shows that there was very little change in tropopause height throughout this period, and there was no great change in the ozone amount. It is reasonable to assume that the average net change of ozone during the five sets of observations was about zero. The mean of these 5 sets and that of 22 May gives the values of the gradients as

$$A=0{\cdot}044,\ B=0{\cdot}040,\ C=0{\cdot}030 \text{ and } D=0{\cdot}030.$$

It is gratifying to note that the values on the days estimated to be 'high' and 'low' are all respectively above or below the values given above.

While it is disappointing that only 19 sets of observations were obtained in six weeks of work and 8 of these have been rejected, this is a case when it is not so important to reduce the random error, by using a large number of sets of observations, as to eliminate as far as possible all systematic errors introduced by variations of haze or ozone amounts.

Final corrections

Hamilton and Walker[3] have shown that if $\mathrm{d}N_A$ . . . . are the errors in the R–N tables for wavelength-pair A . . . . and x_A . . . . are the values of ozone amount determined when these tables are in use, then when the ratios x_A/x_{AD} . . . . are plotted against q the points lie on a line whose slope is

$$\frac{1}{x}\left(\frac{\mathrm{d}N_A}{(\alpha-\alpha')_A}-\frac{\mathrm{d}N_{AD}}{(\alpha-\alpha')_{AD}}\right).$$

When the values x_A . . . . were evaluated using tables corrected by the amounts given above, i.e. by subtracting the values of the gradients from the values of N in the 1962 R–N tables, the slope of the (x_A/x_{AD}, q) lines etc. showed that the errors $\mathrm{d}N_A$ . . . . were not zero. There are not enough equations to enable $\mathrm{d}N_A$ to be uniquely determined, but a least-squares solution gave $\mathrm{d}N_A=-0{\cdot}004$, $\mathrm{d}N_B=0{\cdot}006$, $\mathrm{d}N_C=0{\cdot}002$ and $\mathrm{d}N_D=-0{\cdot}004$. These are random errors arising from the experiment: it is to be noted that errors arising from changes of ozone are not revealed, as these cause changes in the slopes of the regression lines such that $\mathrm{d}N_A/(\alpha-\alpha')_A=\mathrm{d}N_{AD}/(\alpha-\alpha')_{AD}$ etc., and will have no effect on the slopes of the (x_A/x_{AD}, q) . . . . lines.

These errors are the amounts by which the corrections given above are too large. The accepted corrections to the 1962 R–N tables, therefore, are

$$A=-0{\cdot}040 \qquad C=-0{\cdot}032$$
$$B=-0{\cdot}046 \qquad D=-0{\cdot}026.$$

The probable error is estimated to be about $\pm 0{\cdot}005$.

5. INTERCOMPARISON OF SPECTROPHOTOMETERS NOS. 7 AND 51

As the values of T in the 1962 tables were determined by standard lamps from the 1957 Oxford calibration, the corrections quoted in the previous section may be regarded as changes in the extraterrestrial constants. If these are due to changes in the solar spectrum then it is deduced that between 1957 and 1963 there was a reduction in the intensity of the shorter ultra-violet radiation from the sun relative to the longer wavelengths by about 10 per cent over a range of 200 Å. This appeared to be a result of such importance that it was decided to check spectrophotometer No. 7 against another spectrophotometer by making simultaneous direct-sun observations with the two instruments.

Spectrophotometer No. 7 was compared with No. 51 at Lerwick in May 1964. The wedge constants of both instruments were carefully measured by the two-lamp method, and standard-lamp

tests were made using the lamp 7A. R–N tables were computed, based on the measured wedge constants and the same assumed N-value for the standard lamp. When both instruments are illuminated simultaneously by sunlight or skylight, identical N-values would be expected: on the contrary arge differences were obtained:

	N_7	N_{51}	N_7-N_{51}
Wavelength-pair *A*	1.713	1.670	0.043
Wavelength-pair *C*	0.992	0.963	0.029
Wavelength-pair *D*	0.565	0.524	0.041

The differences were slightly greater when simultaneous observations were made on zenith skylight.

Dobson[4] found similar results when he intercompared instruments Nos. 1 and 2 and four new instruments. Differences of the same order of magnitude were found for the *A* wavelength-pairs, though the four new instruments agreed fairly well with one another. In his memorandum Dobson discusses the reason for this, and it is not intended to go further into the matter or to describe experiments with instrument No. 7 which show the same 'directional effect' as he found.

The intercomparisons of spectrophotometers indicate that standard lamps cannot be employed as standard sources having intrinsic N-values, for calibrating spectrophotometers, i.e. for determining their extraterrestrial constants. The 1962 R–N tables, therefore, were invalid and the large corrections determined by the Lerwick 1963 experiment cannot be interpreted as changes in the solar spectrum.

6. CALIBRATIONS AND INTERCOMPARISONS OF INSTRUMENTS NOS. 1 AND 7

Spectrophotometer No. 7 was calibrated by comparison of direct-sun observations against No. 1 at Oxford in 1950: comparisons were made at four points on *C*-wavelengths but at only two each on *A*- and *D*-wavelengths. The wedge constant for *C*-wavelengths was measured, but for *A*- and *D*-wavelengths it was deduced from the direct-sun observations. Values of $R=140$ for *A*, $R=90$ for *C* and $R=60$ for *D* are average dial readings in the range over which observations are normally made, and the N-values derived from this 1950 intercomparison are given in the first line of Table III.

TABLE III. *N-values for spectrophotometer No. 7 by several calibrations at wavelengths A, C and D*

	$A(R=140)$	$C(R=90)$	$D(R=60)$
1950 intercomparison	1·178	0·686	0·398
Corrected 1957	1·210	0·686	0·395
1963 calibration	1·202	0·677	0·380
1966 intercomparison	1·224	0·682	0·374
1966 (uncorrected)	1·134	0·646	0·352

As a result of the 1957 calibration of No. 1, Dobson and Normand[2] concluded that the R–N tables, which were based on solar calibration experiments at Arosa in 1950, should be corrected by +0·032 for *A*, 0·000 for *C* and −0·003 for *D*. Applying these to the 1950 N-values, the correct values in 1957 would be as given in the second line of Table III.

The corrections to the 1950 tables determined by the 1963 solar calibration at Lerwick were +0·024 for *A*, −0·009 for *C* and −0·018 for *D*. When these are applied to the 1950 tables the values in the third line of Table III are obtained.

Finally in 1966 No. 7 was again calibrated against No. 1 (and No. 2) by direct-sun observations at Oxford. The derived N-values for No. 7 are given in the fourth line of Table III.

The significance of the different values in the tables will be discussed later.

7. STANDARD-LAMP TESTS

Standard-lamp tests are carried out monthly on spectrophotometers to check their constancy. The lamp is set in a standard position above the slit of the spectrophotometer, and if the spectral emission of the lamp remains constant the dial reading of the spectrophotometer should remain constant. Changes in dial reading indicate either changes in the spectrophotometer or in the standard lamp.

At Lerwick there are two standard lamps, 7A and 7B: 7A is used for monthly tests, while 7B is only used about once a year. The lamp, the envelope of which is transparent to ultra-violet light, is run from the a.c. mains. By means of a Variac the voltage across the lamp is kept at 200 volts, measured by an Avometer. Early in 1963 the Avometer was replaced by a precision dynamometer voltmeter.

There have been three changes since 1951 which have caused discontinuities in the *R*-values. Up to 1958, standard-lamp observations were made without the ground quartz plate: use of the plate thereafter caused an increase of 3·6. In April 1963 use of the dynamometer voltmeter instead of the Avometer caused a further increase of 0·3. In July 1963—after the calibration of the spectrophotometer—the slits were altered and this caused a further increase of 6·5.

The earlier *R*-values have been corrected for these changes so as to bring them all onto the present standard and the mean values of *R* for wavelength-pairs *C* for each year are plotted in Figure 1. The 1950 value is that of the original lamp test at Oxford. Few observations were made in 1951, but thereafter they became more regular, at a level about 1 lower than the Oxford value. In the mid-1950's the value rose again to a value a little lower than the 1950 Oxford value, and then fell to its lowest value in 1962, since when it has risen to a value nearer to its 1951–53 value. No change took place in the standard-lamp *R*-values when No. 7 was sent to Oxford for the 1966 intercomparison. Observations with 7B have not been made in every year, but it can be seen that they follow the same pattern, and with approximately the same difference. The observations on the other wavelength-pairs, which have only been made since 1958, follow a very similar pattern.

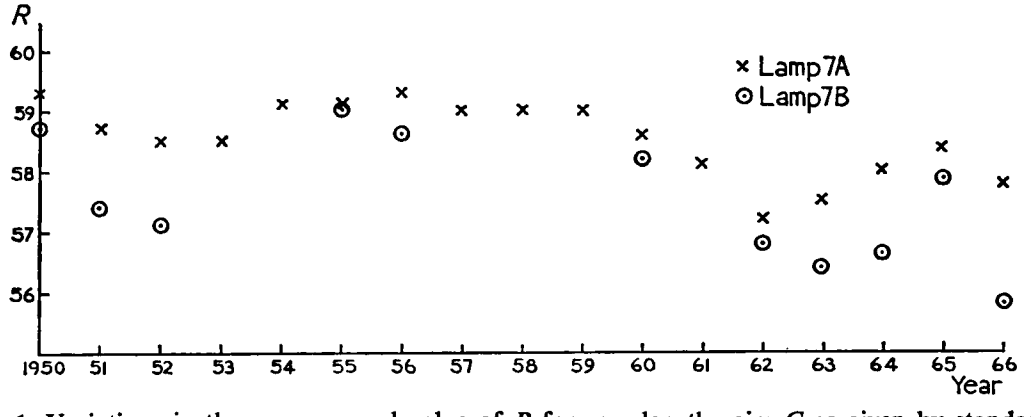

FIGURE 1. Variations in the mean annual value of *R* for wavelength-pairs *C* as given by standard-lamp tests at Lerwick.

It is difficult to account for the variations. It is possible that the more rapid changes in 1960–62 were associated with cleaning and adjustments at the annual inspections which took place in those years, though only at the time of the 1961 inspection was there a discontinuous change, in this case a decrease of about 0·8. (A similar discontinuous increase occurred in 1964). A possible cause could be changes in the waveform of the a.c. mains supply, which might result in changes of power

consumption, and therefore of the N-values for the same voltage as measured by the Avometer voltmeter. The abrupt change between the 1950 Oxford calibration and the subsequent Lerwick standard-lamp tests could be due to the use of two different Avometers. Opposing this theory is the fact that the variations have been just as large in the period of nearly three years since the Avometer was replaced by the dynamometer voltmeter. Moreover experiments show that the N-value of the lamp does not vary rapidly with the voltage: over a range of 190 to 210 volts measured by the Avometer the dial reading changed by only 1·5.

The fact that the two lamps follow similar curves indicates that 7A has not changed owing to use. A slow change in the transparency of the envelope might take place, but one would expect this to be continuous and not fluctuating. However, the standard-lamp readings for No. 7 show much less change than do the standard-lamp readings for other spectrophotometers. Those for No. 1 (and Nos. 2 and 32) change so rapidly that frequent changes are made to the R–N tables, while the changes in No. 7 have never been thought sufficiently large to warrant a change in the tables. The N-values for No. 1 at the time of the 1966 intercomparison were obtained by adding 0·090 for A, 0·036 for C and 0·022 for D to the R–N table deduced from the 1957 Oxford solar calibration.

8. DISCUSSION

The large change in standard-lamp readings of No. 1 indicates the possibility of a change in the constants of the spectrophotometer, making it difficult to determine whether changes have taken place in $\log I_0/I_0'$, the solar part of the extraterrestrial constant. If there were a change in the spectral emission from the sun we might reasonably expect that the shortest wavelengths would be most affected, and that changes in $\log I/I'$ would increase from D-wavelengths to A-wavelengths. Both the 1957 Oxford and 1963 Lerwick solar calibrations indicated rather large positive corrections for A and B, small corrections for C and negative corrections for D. It is difficult to reconcile this with a change in the solar spectrum, and the fact that the Oxford and Lerwick corrections were rather similar suggests that the 1950 Arosa calibration was in error (except for C-wavelengths), and that there were also small changes in the spectrophotometers between the dates of the calibrations.

In view of the rapid change in the standard-lamp readings of No. 1, particularly on A-wavelength, and the rather large error in the solar calibrations, the agreement between the third and fourth lines in Table III may be regarded as being as good as can be expected.

We cannot be certain that changes in the standard-lamp readings indicate changes in the spectrophotometer rather than in the lamp. The evidence, however, is that the lamps do fulfil their function. If the large changes in N-values which have been applied to No. 1 as a result of lamp tests had not been made, the N-values for No. 7 obtained by the 1966 comparison with No. 1 would have been as given in the last line of Table III. These are unacceptably different from the other values, and there can be little doubt that some standard-lamp changes indicate changes in the spectrophotometer constant. This view is confirmed by the fact that the variation in the dial readings with lamp 7B follow the same pattern as those with lamp 7A.

The constancy of the N-values for C-wavelengths in Table III is gratifying for these are the wavelengths which were in general use up to 1957, and for which the corrections determined in the 1957 and 1963 solar calibrations were small. The A- and D-wavelengths were not in use at the time of the 1950 Arosa solar calibration and intercomparisons between No. 1 and No. 7 were made at only two points on the scale on these wavelengths. The Oxford and Lerwick solar calibrations for A were changed, and the drift of the standard-lamp readings on A-wavelengths on No. 1 has been very large. It is not surprising that the agreement for A-wavelengths is not so good. In the case of D-wavelengths larger errors in the solar calibration values must be expected, owing to the greater effect of haze.

Willett[5] has analysed the published ozone values for a large number of stations and has shown that there was a rise in world-wide ozone amounts of 0·035 cm from 1935 to 1941, again 0·035 cm from 1946 to 1952 and a similar increase would be expected from 1957 to 1963. Dobson and Normand[6] have suggested that apparent changes in ozone amount could be caused by changes in log I_0/I_0'. A decrease in log I_0/I_0' of about 0·060 on *AD*-wavelengths, and of about 0·040 on *C*-wavelengths would be required to cause an apparent increase in ozone of 0·035 cm. There is no indication in Table III of changes of this magnitude between 1957 and 1963, or between 1950 and 1957. It seems likely, therefore, that changes in the solar spectrum have not been sufficiently great to be the cause of an apparent cyclic variation of world-wide ozone.

9. MOON OBSERVATIONS

It is useful to be able to make focused moon observations during the winter at high latitudes when otherwise only focused sun observations can be made, and then only for a period of an hour or two around noon when it may well be cloudy. To make such observations it is necessary to determine the extraterrestrial constant of the moon.

If ΔN is the difference between the extraterrestrial constants of moon and sun, then ΔN can be determined in the same way as described in section 4, by making focused moon observations at varying values of q. Owing to the weakness of the source, the accuracy of the observations was not high, but four quite good series of observations on wavelength-pairs *C* were obtained on clear nights when the meteorological conditions indicated that the ozone amount was not changing. These gave values of −0·032, −0·034, −0·035 and −0·030, with a mean value of −0·033. A few *BD* observations were made, for which $\Delta N = 0{\cdot}000$ approximately.

The extraterrestrial constant of the moon was also measured by comparing the results of focused moon observations with focused sun observations made at the previous and following noons. Twelve good sets of observations were obtained: the mean value of ΔN for *C*-observations required to make the moon observations agree with the sun observations was −0·032. For the few *BD* observations ΔN was again about 0·000.

The atmosphere at Lerwick is normally very clear, and observations on the moon were usually made on *C*-wavelengths. These moon observations were particularly useful in measuring ozone amounts during a spell of abnormally high ozone amounts after the 1965/66 winter solstice.

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